

# Two Classes of Gamma-Ray Bursts

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If gamma-ray bursts are at cosmological distances, as suggested by their isotropy on the sky and the comparative deficiency of weak bursts, then they represent radiated energies of  $\sim 10^{51}$  erg, and imply the release of an even greater energy. Only neutron stars and black holes have binding energies sufficient to power such extraordinarily violent and energetic events. General considerations of neutrino opacity imply<sup>1</sup> that the escape of a neutron star's (or black hole's) binding energy requires a time of about 10 sec, as shown by the observed duration of neutrino emission from SN1987A. The distribution of durations of gamma-ray bursts is known<sup>2</sup> to be bimodal, with one peak between 10 and 100 sec and the other between 0.1 and 1 sec. We hypothesize that the durations of the longer bursts may be explained as the result of the diffusion of energy, by means of neutrinos, from a forming neutron star or black hole, but that the brevity of the shorter bursts requires different physics. An alternative hypothesis supposes that all bursts (excepting soft gamma repeaters, which we do not discuss) represent a single class of events, whose differing durations reflect differences in one or more parameters. These two hypotheses may be tested using data from the recently released 3B Catalogue<sup>3</sup>.

We first consider the spectral behavior of gamma-ray bursts. If they are a single class of events, we may expect the spectra of long and short bursts, measured across the entire band over which data are available (from a few tens of KeV to many MeV), to follow a single pattern. If they represent two distinct classes of events, with distinct physical mechanisms and properties, then long and short bursts may have qualitatively different behavior. The 3B Catalogue contains for most bursts a spectral hardness ratio which is the ratio of the count rates in two detectors whose nominal sensitivity bands are 100–300 KeV

and 50–100 KeV; it is a measure of the spectral slope in soft gamma-rays. A small fraction of the bursts are also detected by instruments sensitive to more energetic gamma-rays: COMPTEL (nominally 1–30 MeV), OSSE (0.06–10 MeV) and EGRET (20–30,000 MeV).

The data are summarized in Table 1. We divide the bursts into two classes, short and long, on the basis of whether the duration parameter  $T_{90}$  (the time during which the middle 90% of the fluence arises) is less or more than 10 sec, respectively. Bursts with BATSE hardness ratio  $> 10$  have unusually hard spectra in the soft gamma-ray range; it is these bursts which would be expected to appear in the higher energy detectors if spectral behavior could be simply extrapolated to higher energy.

The data refute this. Almost all the bursts with BATSE hardness ratio  $> 10$  are short, while nearly all the bursts detected by COMPTEL (and all detected by OSSE and EGRET) are long. This establishes that short and long bursts have qualitatively different spectral behavior. The probability that the data shown in the first two lines of Table 1 (BATSE and COMPTEL) could have been drawn from a single population of events is  $< 10^{-8}$ . The OSSE and EGRET data are consistent with the COMPTEL data.

This conclusion can be described in a different way: It is known<sup>2</sup> that short bursts have, on average, larger BATSE hardness ratios than long bursts. It would therefore be expected that short bursts are more likely to be detected at higher photon energies than long bursts. Table 1 shows that the opposite is true. The higher energy photons must be produced by a process which acts in long bursts but not in short ones, establishing that the two classes of bursts differ in more than their durations (or parameters correlated with duration).

The extraordinary burst 3B940217<sup>4</sup> is illustrative of this conclusion, although as a single event it is not statistically significant on its own. It was very long ( $T_{90} = 150$  sec), but produced the most energetic photon (18 GeV) ever observed from a gamma-ray burst, as well as many other photons of  $\sim 100$  MeV energy.

The spatial distribution of long and short bursts may also be compared. We find,

using the 3B Catalogue, that each group is isotropically distributed on the sky to within the limits of statistical accuracy: neither distribution has a significant dipole or quadrupole moment, and neither shows a significant autocorrelation at small angular scales, implying no detectable repetitions. These results confirm those obtained earlier<sup>2</sup> with a smaller sample of data.

The 3B Catalogue contains 251 short bursts with values for  $C/C_{min}$ , where  $C$  is the peak count rate and  $C_{min}$  the detection threshold, and 365 long bursts with values for  $C/C_{min}$ ; the remaining 506 bursts lack  $T_{90}$  or  $C/C_{min}$ . Using these data we evaluated the parameter<sup>5</sup>  $\langle V/V_{max} \rangle$  separately for short and long bursts, with the results  $0.385 \pm 0.019$  for short bursts and  $0.282 \pm 0.014$  for long bursts. Each of these results is significantly less than 0.5, as previously noted<sup>2</sup> for a smaller sample. Combined with the observed isotropy, this implies that each class of burst is at cosmological distances (or, possibly, in an extended Galactic halo). Our new result is that the difference in the values of  $\langle V/V_{max} \rangle$  between short and long bursts is  $0.103 \pm 0.024$ . This is significant at the  $4.3\sigma$  level, very unlikely to have arisen as a statistical fluctuation, and implies that long and short bursts have different spatial distributions.

The observation of this difference in spatial distribution between short and long bursts supports the conclusion that they are different kinds of events. Because this is a quantitative rather than a qualitative difference, it might also be explained if there were a single class of burst whose duration depended on one (or more) parameters, which varied systematically with distance. However, this explanation would not be easy to reconcile with the distinctly bimodal<sup>2</sup> distribution of  $T_{90}$ ; it is more plausible to take this result as supporting the conclusion, drawn from the spectral data, that long and short bursts represent fundamentally different classes of event.

Despite their spectral and statistical differences, long and short bursts qualitatively resemble each other in many ways. Both classes have nonthermal soft gamma-ray spectra, usually with spectral turn-overs in the 100–300 KeV range<sup>6</sup>. Members of both classes of-

ten have complex multi-peaked time profiles, and rapidly rising but more slowly decaying subpulses<sup>7</sup> are common. Although we have argued that long and short bursts must have fundamentally different mechanisms, their similarities are obvious. This phenomenological similarity suggests that the soft gamma-rays of both classes are radiated by similar processes. Only the underlying mechanisms determining their energy release and time scales differ.

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## References

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	$T_{90} < 10 \text{ sec}$	$T_{90} > 10 \text{ sec}$
BATSE Hardness Ratio $> 10$ (0.05–0.3 MeV)	21	1
COMPTEL Detections (1–30 MeV)	4	20
OSSE Detections (0.06–10 MeV)	0	2
EGRET Detections (20–30,000 MeV)	0	6

Table 1: BATSE hardness and high energy detections; nominal sensitivity ranges are indicated. Data are from 3B Catalogue<sup>3</sup>.